VOLUME 76 SEPARATE No. 21

PROCEEDINGS

AMERICAN SOCIETY OF CIVIL ENGINEERS

JUNE, 1950

AMERICAN SOCIETY OF CIVIL ENGINEERS FOUNDED 1852

MAXIMUM LOAD CAPACITY OF BAILEY BRIDGES

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33 W. 39th St.
New York 18, N.Y.

PRICE $0.50 PER COPY

Published at Prince and Lemon Streets, Lancaster, Pa., by the American Society of Civil Engineers. Editorial and General Offices at 33 West Thirty-ninth Street, New York 18, N. Y. Reprints from this publication may be made on condition that the full title of paper, name of author, page reference, and date of publication by the Society are given.

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Founded November 5, 1852

PAPERS

MAXIMUM LOAD CAPACITY OF BAILEY BRIDGES

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Introduction

Full-scale ultimate capacity tests of the Bailey bridge by the Research and Development Laboratories of the Corps of Engineers, United States Army, in 1944, provided basic data for determining the capacity of the structure.[2] This paper explains how the test results were used to determine the maximum military loads that could cross various types of Bailey bridges. This method, developed as a result of the ultimate capacity tests, represents a departure from the strictly analytical methods generally used to determine the capacities of bridges. For the most part, maximum load capacities were increased as a result of the investigation.

The load characteristics and dimensions of military vehicles are known, so that the determination of the maximum load capacity of a military bridge, in terms of these vehicles, is based on more definite information than is ordinarily available to civilian bridge designers. Driver training, plus rigid traffic control at bridges, provides a check to insure that crossing regulations will be enforced. Whereas each civilian bridge is usually designed to satisfy a special set of conditions, military bridges are mass produced to rigid and exacting specifications, with continuous close inspection to guarantee uniformity. These factors, and the urgent necessity to make the maximum use of bridging materials, enable the military designer to reduce the margin of safety to the absolute minimum. Under these conditions and requirements, the most logical basis for the determination of the maximum capacity of a military bridge is full-scale tests to failure.

Loads

The dead load of various spans and types of Bailey bridges was known accurately because the methods of asembly were standardized and the weights of the component parts were known. Actual weights were used in the computations, and equal distribution of the dead load to the trusses on either side of the roadway was assumed.

Note.—Written comments are invited for publication; the last discussion should be submitted by **December 1, 1950.**

[1] Chf. Information Requirements Branch, Program Div. Research & Development Bd., Washington, D. C.

[2] "Testing Bailey Bridges to Failure," by D. Allan Firmage, *Civil Engineering*, April, 1946, p. 154.

In calculations involving live loads, the knowledge of vehicle dimensions, their weight, and their rated load capacities permitted accurate computation of shear and moment. The gross weights of the vehicles were determined on the basis of their rated pay loads. The concentrated load equivalent to 120 military vehicles was computed for spans from 40 ft to 190 ft.

An impact allowance of 10% of the live load was made for all types and classes of vehicles on all the spans. Limited dynamic impact tests, using electrical strain gages and recorders, indicated that a flat 10% impact allowance was adequate for military bridges. The maximum load capacity of these bridges was actually determined by relatively heavy, slow-moving, tracked vehicles and the impact of these vehicles is reduced to a minimum by the combined cushioning effect of their track-laying action and the action of their bogie wheels.

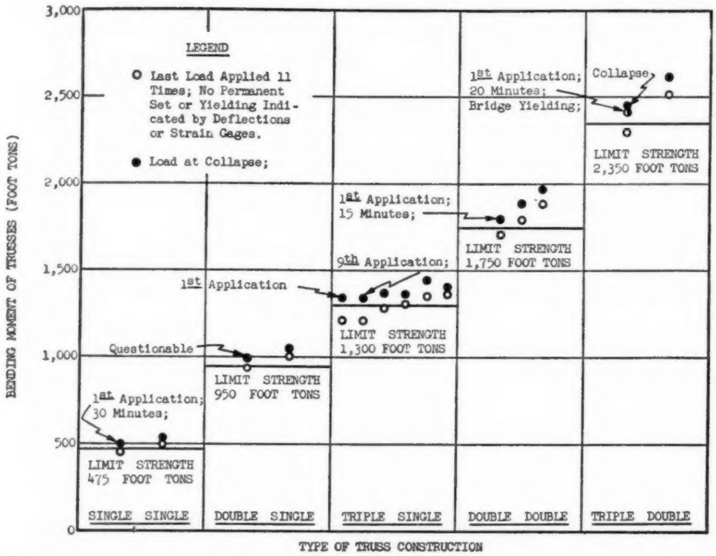

Fig. 1.—Limit Strengths of Bailey Bridge Trusses As Determined from Results of Ultimate Capacity Tests

Additional dynamic impact tests are being conducted to substantiate or revise the present 10% allowance.

A final load factor requiring consideration was the effect of eccentricity of the vehicle. Since the Bailey bridge has a single-lane roadway, the vehicles were placed against the curb to obtain maximum eccentricity. Using the floor beam as a simple beam supported by the side trusses at their center of gravity the load carried by the side trusses was computed. Doubts as to the correctness of this procedure were eliminated by the results of the ultimate capacity tests.

Margin of Safety

The resisting moment of a bridge at failure, determined on the basis of ultimate capacity tests, was defined as its limit strength. The results of the tests and the chosen limit strengths are shown in Fig. 1. The word "chosen"

is used because the choice was arbitrary, since in most cases only two bridges were tested. Notes made in Fig. 1 describe the failure of each type of bridge that carried the least load. Generally the limit strength was determined to the nearest 25-ft tons midway between the last load carried satisfactorily and the load causing failure. "Carried satisfactorily" meant that a given load was applied eleven times without either yielding or permanent set being indicated by electrical strain gage or deflection measurements.

Before selecting a value for the margin of safety, three types were considered (Fig. 2). Type I was a constant margin of safety on live load only. Type I had the disadvantage that on long spans, which would carry only light vehicles, the over-all margin of safety was very low. Even though the dead load was known accurately, and high efficiency to save materials was desirable, the possibility that overloading would occur simultaneously with an unusual impact ruled out this type of safety factor. Type II, a constant margin of safety on the dead and live loads, was adopted. It provided maximum efficiency in the short span range where vehicles were heavy, their weights accurately known, and impact

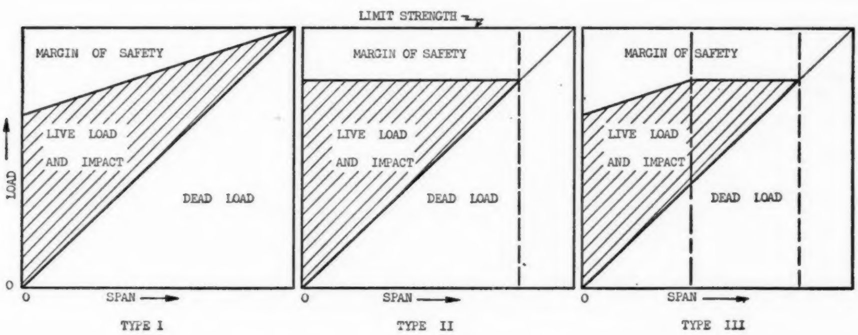

Fig. 2.—Three Types of Margin of Safety

was generally at a minimum because of the track-laying characteristics of the governing vehicles. In addition, it was adequate for the lighter vehicles on long spans and it was easy to apply. Type III was a compromise between Types I and II. The beginning of Type II could have been determined on the basis of span length or on the ratio of dead load to live load. As illustrated, Type I was used when the ratio was less than 1; and Type II, when it was greater. This type of safety factor was not used because it did not make efficient use of the materials on short spans and because, in practice, it was the most difficult to apply. The three types of margin of safety and their relation to total load and live load plus impact are compared in Fig. 3. The assumption was made that when the ratio of dead load to live load was 1, they were identical. The margin of safety of Type II which was adopted is a constant on the total load; it is low for large live loads; and it increases as the live load decreases and the span increases.

The actual value of the margin of safety was based on the consideration of three factors—the determination of the limit strength by ultimate capacity

tests, the rigid traffic control regulations, and the effects of the load on the structure. These are summarized in Table 1 with the design criteria that resulted from their evaluation.

Traffic control regulations permitted three types of crossing. "Control" crossings were relatively unrestricted. Vehicles moved at normal convoy speed and spacing, and could use any part of the roadway. After use as a "control" crossing the bridge could be disassembled, and re-erected time and again at new sites. The several parts of the bridge were "standardized" so that new parts or used parts from other sites could be used interchangeably. This requirement fixed the maximum "control" load as one that would not cause permanent deformation or local stresses exceeding the yield point. These stress criteria also applied to "caution" crossings, which differ from "control"

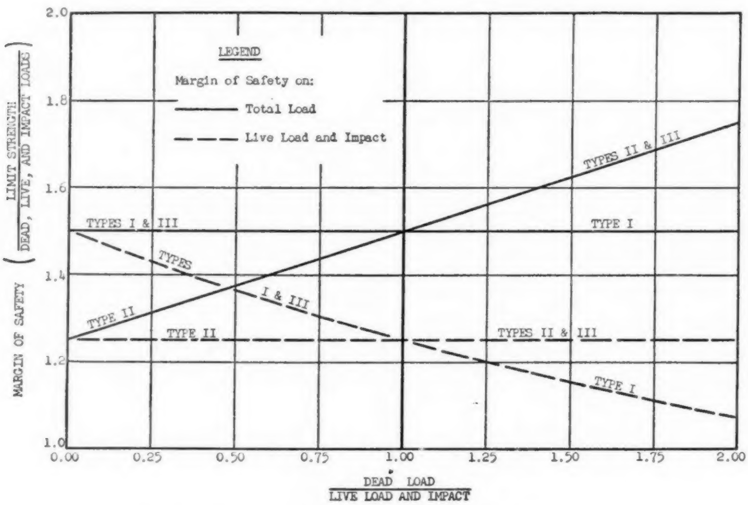

FIG. 3.—COMPARISON OF TYPES OF MARGIN OF SAFETY

crossings in that the interval between vehicles is increased, speed is reduced, movement is continuous, and the vehicle must travel on the center line of the roadway. A military expedient, and still higher classification than the foregoing, was the "risk" type of crossing. It is all that its name implies, with the possibility that when it is used it may cause the bridge to collapse. Local stresses were permitted to exceed the yield point and permanent deformation could prevent re-use of some of the bridge parts. Traffic control regulations for this type of crossing are similar to the "caution" crossing but more rigid; speed is reduced to a minimum and only 1 vehicle is permitted on the bridge at a time.

The design criteria corresponding to "risk", "caution", and "control" crossings translated the traffic control regulations into simple specifications for bridge design—axle or track spacings for vehicles and an eccentricity of 6 in.

TABLE 1.—Traffic Control, Design Criteria, and Bridge Effects for "Risk," "Caution," and "Control" Loads

Manner of crossing	Traffic control regulations	Effects of load on bridge	Design criteria
"Risk"	Walking guide. Single vehicle. Speed, 2 miles per hr to 3 miles per hr. Continuous movement; no shifting, braking, or stopping. Vehicle on center line of bridge.	Localized stresses exceeding yield point practically a certainty. Remote possibility of collapse. Constant and repeated use of structure for "risk" loads may eventually result in collapse. Parts of structure will be deformed or actually broken so that re-use will not be possible.	Single vehicle on bridge. Eccentricity of 6 in. No impact. Weakest part of structure will be stressed to 90% of limit strength as determined by small number of ultimate capacity tests.
"Caution"	Vehicles spaced 50 yd, nose to tail. Speed, not more than 5 miles per hr. Continuous movement, no shifting, braking, or stopping. Vehicle on center line of bridge.	Localized stresses below yield point of material. No possibility of collapse if traffic control regulations are properly enforced. Repeated "caution" crossing will not result in collapse. All parts of structure will be available and serviceable for re-use unless damaged by accident.	Vehicles spaced 150 ft from rear axle of lead vehicle to front axle of second vehicle or from rear of ground contact of lead vehicle to front of ground contact of second vehicle. Eccentricity of 6 in. No impact. Weakest part of structure will be stressed to 80% of limit strength as determined by small number of ultimate capacity tests.
"Control"	Vehicles spaced 30 yd, nose to tail. Speed, not more than 25 miles per hr. Vehicles not required to stay on center line.	Localized stresses below yield point of material. No possibility of collapse if traffic control regulations are properly enforced. Repeated "caution" crossing will not result in collapse. All parts of structure will be available and serviceable for re-use unless damaged by accident.	Vehicles spaced 100 ft from rear axle of lead vehicle to front axle of second vehicle or from rear of ground contact of lead vehicle to front of ground contact of second vehicle. Maximum eccentricity; vehicle against curb. 10% impact. Weakest part of structure will be stressed to 80% of limit strength as determined by small number of ultimate capacity tests.

for vehicles theoretically on the center line. No impact allowance was used for "caution" and "risk" crossings. The effects of the load on the bridge were specified in terms of the margins of safety that allowed for uncontrollable variations, such as slight variations in material, fabrication, and field erection. They did not allow for variations that could be minimized through traffic control, such as overloading, impact, and eccentricity. For both "control" and "caution" crossings the maximum permissible load is 80% of the load that might cause collapse. This is 80% of the limit strength, or a margin of safety of 1.25 on failure. The margin of safety on "risk" loads is 1.11, or 90% of the limit strength.

These values of the margin of safety were based on the testing to failure of a limited number of bridges. However, if more bridges of one type were tested, the test data could be analyzed statistically to determine the limit strength; and, based on a limit strength determined in this manner, the margin of safety might possibly be lowered.

Stresses

The margins of safety have been applied to the results of a bridge test in Fig. 4. This was the double-double truss bridge that carried the least load of

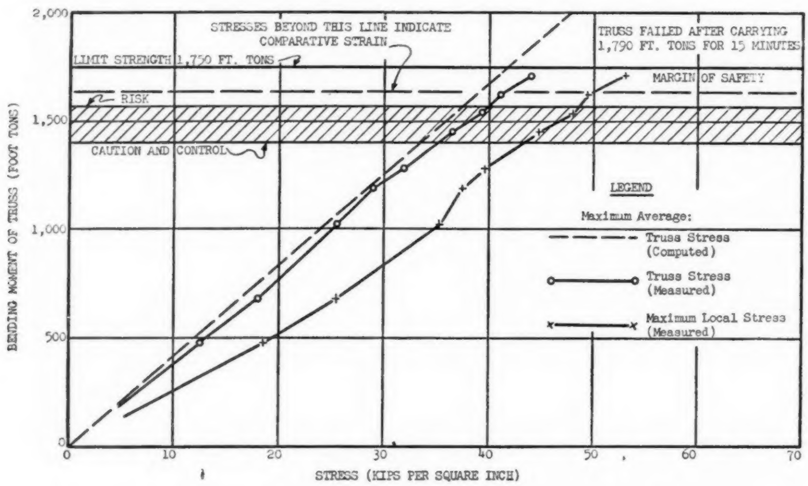

Fig. 4.—Criteria for Maximum Load Capacity Applied to Test Results of 130-Ft Double-Double Truss

the three bridges of this type tested. For "caution" and "control" crossings the average truss stress was 35,200 lb per sq in. and the maximum local stress was 43,000 lb per sq in. For "risk" loads these stresses were 39,500 lb per sq in. and 48,300 lb per sq in., respectively. At limit strength the computed truss stress was 42,000 lb per sq in. In the other two double-double bridges tested it was measured as 41,900 lb per sq in. and 42,200 lb per sq in. Similar data for all the test bridges are presented in Table 2. All the maximum local stresses at limit strength and half of those for "risk" loads exceeded the guaranteed yield

point of the material, 50,000 lb per sq in. Test samples of the material showed actual yield points varying betweeen 50,000 lb per sq in. and 60,000 lb per sq in. The guaranteed minimum tensile strength of the material was 70,000 lb per sq in., and actual test sample results varied from 73,000 lb per sq in. to 87,000 lb per sq in. In general, the measured stresses were low compared to the computed average truss stresses, except where the strain gages indicated maximum local strains above the yield point. The only notable exception was the second 130-ft double-double bridge. Careful check of the original data indicated no explanation for the higher strains actually recorded. An important point to

TABLE 2.—Maximum Compression Chord Stresses, in Kips per Square Inch, Measured During Ultimate Capacity Tests

Test bridge No.	Limit Strength			"Risk"			"Caution" and "Control"		
	Average Truss Stress		Maximum local stress	Average Truss Stress		Maximum local stress	Average Truss Stress		Maximum local stress
	Computed	Measured		Computed	Measured		Computed	Measured	
60-Ft Single-Single:									
1	47.2	..	..	42.5	37.4[a]	57.0[b]	37.8	32.7	40.9
2	47.2	47.1[a]	86.5[b]	42.5	40.8[a]	51.5[b]	37.8	35.0	39.8
100-Ft Double-Single:									
1	47.2	..	..	42.5	36.0[a]	54.7[b]	37.8	31.2	34.3
2	47.2	48.6[a]	58.9[b]	42.5	39.9	46.5	37.8	35.0	40.0
110-Ft Triple-Single:									
1	43.0	47.0[a]	83.6[b]	38.8	36.7[a]	56.6[b]	34.5	31.9	45.5
2	43.0	37.7[a]	50.5[b]	38.8	32.6	39.6	34.5	28.8	33.5
130-Ft Triple-Single:									
1	43.0	38.4[a]	52.0[b]	38.8	34.6	42.6	34.5	31.4	39.0
2	43.0	..	..	38.8	35.5[a]	50.4[b]	34.5	31.8	43.4
140-Ft Triple-Single:									
1	43.0	47.9[a]	87.9[b]	38.8	40.4[a]	58.3[b]	34.5	35.7	48.1
2	43.0	..	..	38.8	33.8	43.0	34.5	30.0	37.0
130-Ft Double-Double:									
1	42.0	41.9[a]	57.0[b]	37.8	36.5	48.0	33.6	32.9	41.9
2	42.0	..	..	37.8	39.5	48.3	33.6	35.2	43.0
3	42.0	42.2[a]	..	37.8	36.6	..	33.6	33.3	..
150-Ft Triple-Double:									
1	37.6	37.7[a]	55.0[b]	33.9	32.4	43.1	30.1	28.4	36.6
2	37.6	43.9[a]	..	33.9	33.9[a]	55.7[b]	30.1	29.1	40.9

[a] These average values include individual stresses above yield point (50,000 lb per sq in.) and therefore are not true stresses but indicate comparative strain. [b] These values were converted from strains that exceeded the yield point and therefore are not true stresses.

note in Table 2 is that, because of the nature of the built-up trusses in the Bailey bridge, and the use of the limit strength based on ultimate capacity tests, the computed maximum allowable average stress was not the same for all types of trusses. Prior to the ultimate capacity tests, the maximum "control" loads were determined from computed stresses with a maximum allowable average truss stress of 30,200 lb per sq in. This allowable stress has now been increased to 37,800 lb per sq in. for the single and double-single types of trusses. The ultimate capacity tests were primarily responsible for this increase in allowable capacity. Increased capacities were also permissible for the other types of trusses with only an insignificant decrease for the triple-double type. The

ultimate capacity tests also permitted the introduction of "risk" crossings, a necessary and desirable military expedient. This classification was not possible on the basis of computations alone, because it was known that they were not sufficiently exact for that purpose.

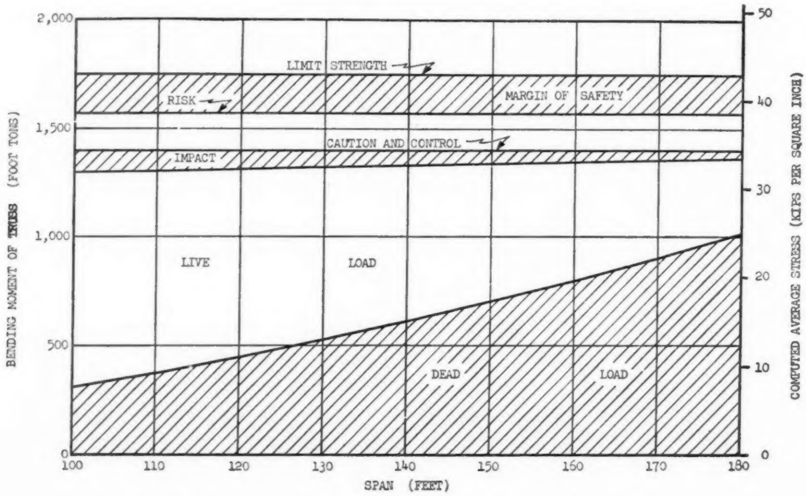

FIG. 5.—USE MADE OF MOMENT CAPACITY OF DOUBLE-DOUBLE TRUSSES

FIG. 6.—TOP CHORD FAILURES OF SINGLE TRUSS, DOUBLE TRUSS, AND TRIPLE TRUSS BAILEY BRIDGES

The use made of the truss capacity of a common type of Bailey bridge construction is shown in Fig. 5. For spans less than 100 ft this type of construction was uneconomical and for spans longer than 180 ft it could not be erected by the normal cantilever method of launching. Thus far, all discussion has dealt with moment capacity. For the Bailey bridge spans commonly used, moment gov-

erned, and failure occurred by buckling of the top chord of the trusses (see Fig. 6). Shear did govern in some types of trusses up to spans of 80 ft. Ultimate capacity tests were conducted and limit strengths were determined for shear. The foregoing principles for moment were applied for shear with the same margins of safety.

TABLE 3.—SAFE AND "CAUTION" CAPACITIES OF VARIOUS TYPES OF BAILEY BRIDGES, IN TONS

Span (ft)	Single-Single		Double-Single		Triple-Single		Double-Double		Triple-Double	
	"Control"	"Caution"	"Control"	"Caution"	"Control"	"Caution"	"Control"	"Caution"	"Control"	"Caution"
40	32	45	..	..	..	..	..	..	..	..
50	28	38	80	100	..	..	..	..	..	..
60	24	32	67	84	..	..	..	..	..	..
70	20	27	57	71	..	..	..	..	..	..
80	17	23	48	60	75	94	..	..	..	..
90	13	18	40	50	62	78	..	..	..	..
100	10	13	31	40	50	63	75	94	..	..
110	..	..	23	31	40	50	61	76	80	100
120	..	..	18	23	31	41	50	63	67	84
130	..	..	13	18	23	32	40	51	57	71
140	..	..	10	13	18	23	31	40	48	61
150	..	..	..	..	13	18	23	32	39	50
160	..	..	..	..	10	13	18	25	31	40
170	..	..	..	..	..	..	13	19	23	31
180	..	..	..	..	..	..	10	13	18	23
190	..	..	..	..	..	..	..	..	12	16

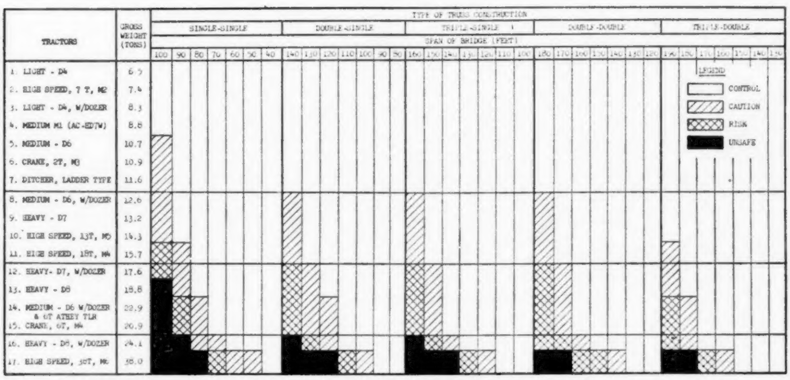

FIG. 7.—CAPACITY OF BAILEY BRIDGES

APPLICATION

For each type and span it was determined in what manner, "risk," "caution," or " control," each of 120 military vehicles could cross. Tables were set up for each bridge, giving live load, shear, and moment capacity for each type of crossing. Similar tables were set up for each vehicle in terms of its concentrated load equivalent. These tables accounted for the length of track or number of axles of the vehicle on the span (whether one or more vehicles were on the bridge), the impact, and the maximum (6-in.) eccentricity. Comparison of these

tabulated data produced graphical bar charts such as that shown in Fig. 7. On the basis of the gross load system of vehicle classification used by the Army, the bar charts were reduced to tabular form as shown in Table 3. These data for "control" crossings were plotted as shown in Fig. 8.

The bridge capacity data were published in all three forms as bar charts, tables, and graphs. Each had a preferred use, and only the bar charts were complete. The tables did not contain data on "risk" loads, and the graphs showed only the "control" loads. The graph was used to determine the type of bridge to be constructed which would carry the maximum expected load for the given site. Table 3 had the same purpose and if a "caution" rating was speci-

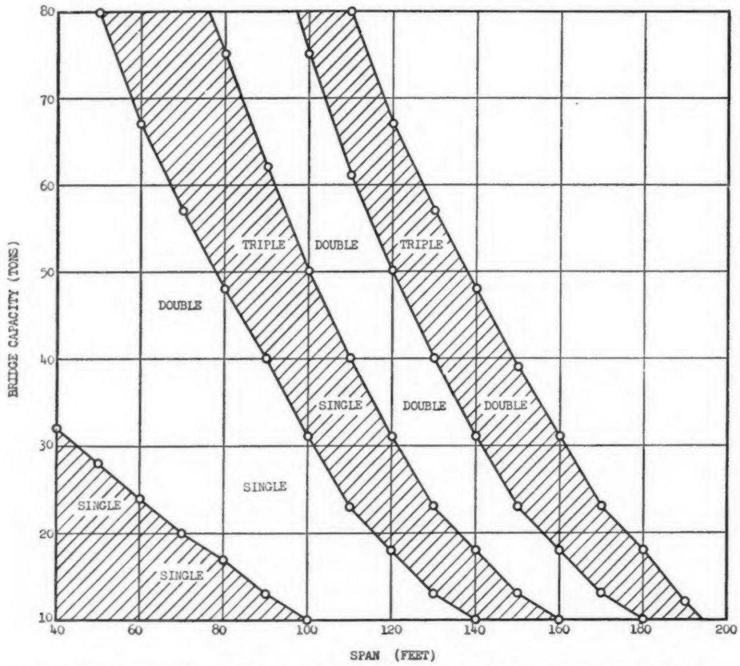

FIG. 8.—BAILEY BRIDGE TRUSS CONSTRUCTION FOR VARIOUS LOADS AND SPANS

fied for the route it had to be consulted. The bar chart determined the safety of passage for individual vehicles and was the only published data on "risk" crossings. Bridges were posted with their "control" capacity in tons but the rounding off of these values, necessitated by the gross load system for classifying vehicles, prohibited the use of certain bridges to some vehicles that could cross as shown by the bar chart. In all cases the bar charts were the final authority. The general rule for overloaded vehicles was that they cross as the next higher restricted class of load. For example, an overloaded vehicle, normally a maximum "control" load, could cross as a "caution" load, a "caution" load could cross as a "risk" load and a vehicle normally a "risk" load would be forbidden passage.